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Holger L. Brencher  
*Pacific University*

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# Air-puff tonometry: A clinical comparison of current instruments to the Goldmann applanation tonometer

## Abstract

The purpose of this investigation was to clinically compare the Topcon CT-10, Reichert XPERT NCT, Reichert NCT II, and Keeler PULSAIR air-puff tonometers to the Goldmann applanation tonometer. Two hundred and twenty-seven subjects (452 eyes) ranging in age from 8 to 86 and presenting intraocular pressures from 6 to 40 mm Hg participated in the study. Mean IOP values for all air-puff tonometers, except the Reichert NCT II, were statistically significantly different from the Goldmann findings. The Topcon CT-10 read slightly higher in most pressure ranges, with the two Reichert instruments reading closest to and the Keeler PULSAIR reading lower than Goldmann in most pressure ranges. The differences were not considered clinically relevant. Subjects selected the XPERT NCT as the most preferred and the NCT II as the least preferred air-puff tonometer. The majority of the respondents attributed their selection to the intensity of the air puff. The new generation of air-puff tonometers offer distinctive design improvements, as well as increased patient comfort, but provide no greater reliability than the original NCT air-puff tonometer.

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Master of Science in Vision Science

## Committee Chair

Paul Kohl

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tonometry, air-puff tonometers, goldmann applanation tonometer, intraocular pressure, xpert nct tonometer, pulsair tonometer

## Subject Categories

Optometry

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AIR - PUFF TONOMETRY:  
A CLINICAL COMPARISON OF CURRENT INSTRUMENTS  
TO THE  
GOLDMANN APPLANATION TONOMETER

A Thesis Presented to Pacific University College of Optometry  
For The Degree Master Of Science  
In  
Clinical Optometric Management

by

Holger L. Brencher, O.D.

COMMITTEE MEMBERS

Paul Kohl, O.D.  
Robert L. Yolton, O.D., Ph.D.  
A. Richard Reinke, O.D.

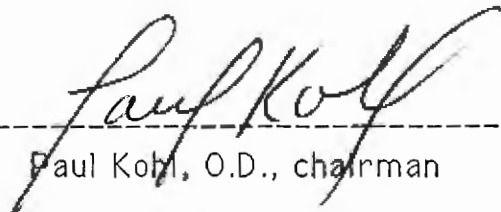
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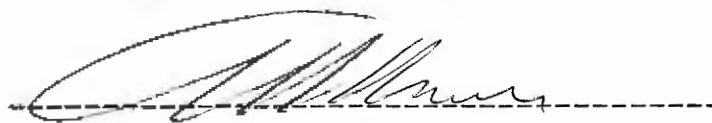
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Major Holger L. Brencher, O.D., U.S. Army

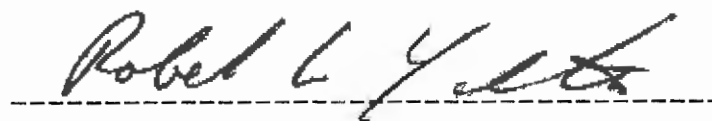
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Paul Kohl, O.D., chairman



A. Richard Reinke, O.D.



Robert L. Yolton, O.D., Ph.D.

## Abstract

The purpose of this investigation was to clinically compare the Topcon CT-10, Reichert XPERT NCT, Reichert NCT II, and Keeler PULSAIR air-puff tonometers to the Goldmann applanation tonometer. Two hundred and twenty-seven subjects (452 eyes) ranging in age from 8 to 86 and presenting intraocular pressures from 6 to 40 mm Hg participated in the study. Mean IOP values for all air-puff tonometers, except the Reichert NCT II, were statistically significantly different from the Goldmann findings. The Topcon CT-10 read slightly higher in most pressure ranges, with the two Reichert instruments reading closest to and the Keeler PULSAIR reading lower than Goldmann in most pressure ranges. The differences were not considered clinically relevant. Subjects selected the XPERT NCT as the most preferred and the NCT II as the least preferred air-puff tonometer. The majority of the respondents attributed their selection to the intensity of the air puff. The new generation of air-puff tonometers offer distinctive design improvements, as well as increased patient comfort, but provide no greater reliability than the original NCT air-puff tonometer.

## Key Words

Tonometry, air-puff tonometers, GOLDMANN Applanation Tonometer, intraocular pressure, XPERT NCT Tonometer, PULSAIR Tonometer, NON-CONTACT II Tonometer, CT -10 Tonometer.

## Introduction

The ophthalmic literature supports the premise that the accurate measurement of intraocular pressure (IOP) is not only important in the diagnosis and treatment of glaucoma, but that it should be an inherent part of every ocular examination. The literature supports Goldmann applanation tonometry as the accepted standard for this diagnostic procedure.<sup>1,2</sup>

Although Goldmann applanation tonometry is generally considered the "gold" standard against which all other types of tonometers are compared, it does have performance limitations. Factors such as: requirement for corneal anesthesia, possibility of microbial contamination, low portability, restricted use in young or bed-fast patients, slit-lamp requirement, and subjectivity to errors of technique, must be considered when comparing the benefits of other tonometric procedures to Goldmann tonometry.<sup>3-5</sup>

The first 'non-contact' tonometer was introduced by Grolman in 1972.<sup>5</sup> Since that time 'non-contact' or air-puff tonometry has proven to be a safe, valid and widely accepted ophthalmic procedure.<sup>4,5,6</sup> The advantages of the air-puff tonometers (the correct nomenclature since "Non-Contact" is a patented trade name of the Reichert instruments) over other types of tonometers are : (1) IOP measurements can be made without the need for corneal contact or anesthesia. This of course minimizes the possibility of corneal trauma, infection spread, and drug reactions. (2) Use by paraprofessional personnel with minimal training can provide



reliable results. (3) Repeated measurements produce no significant alteration of the IOP or corneal trauma.<sup>7,8</sup>

No new instruments or significant design modifications of the original Non Contact Tonometer(NCT) occurred for many years after air-puff tonometry was introduced.<sup>5</sup> Recently, Keeler Instruments Inc. (PULSAIR)<sup>a</sup>, Topcon Instruments Corp. of America (CT-10)<sup>b</sup>, and Reichert Ophthalmic Instruments (EXPERT and NCT II)<sup>c</sup> have each introduced a new design air-puff tonometer.

Air-puff tonometry, as well as other forms of applanation tonometry, are based in theory on the Imbert-Fick Law, which states that the force required to applanate a given corneal area is directly proportional to the IOP.<sup>5,9</sup> With air-puff tonometry, the force that produces applanation is provided by a pulse of room air, generated by the pneumatic system of the instrument. The instrument's opto-electronic applanation monitoring system, measures the amount of reflected light off the cornea, and thereby detects the exact moment of applanation.

In the Reichert tonometers ( XPERT NCT and NCT II ), an electronic clock measures the time from which the air-puff is generated, until the monitoring system's reception of the maximum corneal reflection signal (at applanation). The measured time intervals, which have all been calibrated against Goldmann measurements, are converted to IOP and numerically displayed in the instrument. The Topcon ( CT-10 ) and the Keeler ( PULSAIR ) instruments make use of a pressure transducer to instantaneously sample the pressure at the time that the monitoring system detects

applanation of the cornea. That pressure is then displayed by the instrument as the IOP.<sup>7,10,11,12</sup>

Air-puff tonometers also rely on an alignment system to properly orient the instrument to the patient's cornea. The NCT and the current NCT II require the examiner to manually initiate the measurement once alignment has been achieved. The CT-10, the XPERT NCT, and the PULSAIR instruments feature an auto-measurement system, which automatically releases the applanating puff of air after proper alignment has been achieved. This system is designed to reduce the possibility of operator error, since readings can only be obtained when the instrument is properly aligned.<sup>12</sup> Both the CT-10 and the EXPERT instruments are still also equipped with a manual measurement system.

The following is a brief description of each of the air-puff tonometers:

**Topcon Computerized CT-10** – (figure 1) – features a built in TV monitor to facilitate alignment of the instrument to the patient, an automatic measurement mode that automatically initiates a measurement within milliseconds after proper alignment is achieved, an automatic shut-off to protect the monitor, and a built in printer. The instrument is table or stand mounted and requires a patient posture similar to the NCT II.

**Reichert XPERT NCT (prototype)**– (figure 2) – features a built-in TV monitor alignment system, automatic measurement mode, a built in printer, and computer compatibility via a RS 232 port. The instrument is table or stand mounted. Based on the manufacturer's

claims this will be the most sophisticated computerized non-contact tonometer on the market.

**Reichert NCT II** - (figure 3) - except for two cosmetic changes (a push-button operation panel replacing the former rotating switch on the NCT and a light-emitting diode display of the IOP to replace the old NIXIE tube) and an updated electronic circuit, this model very closely resembles the original Non-Contact Tonometer. The current model has been in clinical use for over fourteen years. It does not feature a built-in TV monitor alignment system, auto-measuring mode, and built in printer. The instrument is table or stand mounted.

**Keeler PULSAIR** - (figure 4) - is a hand-held air-puff instrument which makes it useable with patients unable to follow directions, fixate or align in a chin rest. The hand-held tonometer is attached by a flexible cable to a compressor unit. Air is stored in a tank of this unit and is released when the measurement occurs. Measurement is automatic once proper instrument to cornea alignment is achieved. Unlike the other air-puff tonometers, this instrument utilizes no piston to produce the air pressure. The instrument can be wall or desk mounted, or used on a mobile cart.

The CT-10, XPERT NCT, AND PULSAIR are advertised as providing more patient comfort. These claims are based on the use of a lower level of air-puff pressure in the instruments. This result is achieved by producing an air-puff with just enough pressure to only slightly exceed the point of applanation, rather than applying a fixed high level of air pressure common for all patients.

Although many studies have compared the NCT and the NCT II to Goldmann applanation tonometry, very few articles have been published concerning the CT-10, The EXPERT, and PULSAIR.<sup>4-6, 10-13</sup> No investigation has made a one time comparison of all four instruments on the same subject population. Considering that air-puff tonometry is one of the most frequently performed tonometric procedure, the need was recognized for a study to clinically evaluate the new and existing air-puff tonometers against Goldmann applanation tonometry.<sup>7</sup> The goal of this study was to identify any performance differences between the instruments of the study and to evaluate any preferential acceptance of the tonometers by the subject population.

### **Methods**

The 228 (452 eyes, two monocular subjects) subjects that participated in the study ranged in age from 8 to 86 and were recruited via news stories or from Optometry Clinic recall files. There were 126 female and 101 male subjects. All were offered a vision examination in compensation for their participation. Prior to any testing, subjects were informed that they would be asked to complete a brief instrument preference questionnaire at the completion of testing .

All testing was done in one location in the College of Optometry Outpatient Clinic. The examiner was a military optometrist with over 12 years of clinical experience. This experience included performing thousands of Goldmann and NCT applanation procedures. To insure skilled use of the new instruments, a three day training period was included in the study protocol. It was found that, although the

alignment method of each of the new tonometers were slightly different, each required only 10-15 practice trials skilled performance was acquired.

The numbering of instruments ( see Appendix A ) was done to facilitate computerized randomization of testing order, statistical analysis, and to help provide instrument identification for the study subjects without name bias. To facilitate subject movement, the five instruments were arranged side by side in the testing room. To insure similar subject postural position, instruments were located on adjustable stands and subjects were seated on adjustable stools. All readings were taken with the subjects in an upright seated position. All instruments were checked and calibrated daily according to the manufactures' instructions. Specific instrument testing procedures were as follows:

*Topcon CT-10 , Reichert EXPERT and NCT II-* Three readings per eye were taken with the CT-10 and XPERT NCT in the "auto" mode and the NCT II in the manual alignment position. Low confidence readings as indicated by an "asterik" on the XPERT NCT, a parenthesis on the CT-10 or a blinking reading on the NCT II were not accepted.

*Keeler PULSAIR-* Four readings were taken per eye according to the manufactures recommendations. No readings in the "subflex" mode (for eyes with corneas of reduced or distorted reflectivity) were taken.

*Goldmann Applanation Tonometry -* Three readings per eye were obtained with a calibrated Haag Streit AG Goldman tonometer. Following topical corneal anesthesia and staining (Fluress - 0.25% sodium flourecein with 0.4% benoxinate HCL) a series of three blind

(dial masked) successive measurements per eye were taken, the instrument being reset to the 1 (10 mm Hg ) position after each measurement. All tono tips were disinfected in 3% hydrogen peroxide between patients.

NCT II and XPERT NCT instruction manuals recommend data screening for "FLYERS", or readings that "appear to be irrelevant or erroneously high." It is advised that such a readings be considered "disparate" and therefore be replaced with a new measurement. Unfortunately, the manuals do not specify at what numerical value a reading becomes "irrelevant or erroneously high". The manuals do present examples however, as well as stating that, "normal measurement fluctuations of 2 to 4 mm Hg must be anticipated due to the cardiac-related pulse amplitude." Based on the examples and the pulse statement, the assumption can be made that the "FLYERS" are any reading that creates a range of 5mm or greater for the three acceptable readings. Such a situation occurred in a total of fourteen eyes in this study ( 8 NCT II and 6 XPERT NCT ). The CT-10 and PULSAIR instruction manuals do not make such a recommendation. For procedural conformity, this study chose not to reject any readings based solely on the 5mm range criterion.

The instrument testing sequence for each subject was randomized for the air-puff tonometers. Goldmann tonometry was always done last to minimize any possible applanation effect.<sup>4</sup> Biomicroscopy and visual acuity testing were performed on each subject prior to and after testing.

The total measurement time for all five instruments averaged fifteen minutes. At the completion of the measurement procedures,

each subject was asked to complete the questionnaire. They were asked to choose which of the air-puff tonometers they liked the most and which one they liked the least. The subjects were also requested to give reasons for their choices.

## Results

Data were collected from a total of 228 subjects (452 eyes). For increased data point and wider pressure range considerations, right and left eyes per subject were treated independently. Mechanical breakdown of the prototype XPERT NCT after the 149th subject required the raw data to be arranged and analyzed in two groups. Group 1 represents readings taken by the Goldmann and all the air-puff tonometers on the first 298 eyes. Group 2 represents readings of all the eyes measured (1-452), exclusive of the XPERT NCT values. The data for the two groups are shown in Tables 1 and 2.

The mean IOP's for the instruments in group 1 (all air-puff tonometers, 298 eyes) were as follows: CT-10 =16.32 mm Hg with a SD of 4.59 mm Hg, XPERT NCT =15.56 mm Hg with a SD of 4.58 mm Hg, NCT II =14.21 mm Hg with a SD of 4.58 and the PULSAIR =12.06 mm Hg with a SD of 3.99 mm Hg. Mean IOP's for the Goldmann were 14.44 mm Hg with a SD of 4.22 mm Hg. The CT-10 minimum measurement was 7 mm Hg and the maximum 55 mm Hg. The XPERT NCT minimum reading was 7 mm Hg and the maximum 51 mm Hg. The NCT minimum reading was 6 mm Hg and the maximum 50 mm Hg. The Pulsair minimum and maximum readings were 3 and 35 mm Hg. The Goldmann minimum and maximum values were 6 and 41 mm Hg. The standard deviation of the differences of the means,  $Sp$ , for group 1 were: CT-10 = 2.66, XPERT NCT=2.79, NCT II= 2.74, PULSAIR= 2.89,

all values in mm Hg ( see Table 1 ). For group 2 data see Table 2. A one-factor analysis of variance (ANOVA) and a Scheffe F-test post analysis with a 90% level of significance for Group 1 data, revealed a significant difference of all mean value comparisons except those between the NCT II and the Goldmann. Results of a one-factor ANOVA of the data in Group 2 were similar.

The mean and SD values for the Range (high to low readings) are also listed in Tables 1 and 2. The mean of the Range values for group 1 and 2 were similar. In Group 1 (eyes 1-298) the values were: CT-10= 2.19, XPERT NCT= 2.54, NCT= 2.12, PULSAIR= 5.42, Goldmann= 1.30, all values in mm Hg. The maximum and minimum Ranges of IOP readings for any individual for each instrument are presented in Tables 1 and 2. A one factor ANOVA with a 90% level of significance, for Range data revealed a significant difference between all instruments in the study.

Correlation curves comparing Goldmann and air-puff tonometers were constructed (see Figures 5-8, 5a-7a). The correlation coefficients from the regression curves for Group 1 were: CT-10 = .82, XPERT NCT = .82, NCT II = .81, PULSAIR = .76 . The results for group 2 (452 eyes) were virtually the same (see table 4).

The air-puff instruments performance relative to Goldmann tonometry are illustrated by the graphs in Figures 9 and 10. These graphs display the mean differences from Goldmann for each air-puff tonometer for pressures found in this study. The Goldmann mean IOP values are represented by the "0" baseline on the y axis. The differences of the mean of each air-puff tonometer from the Goldmann value, for each particular Goldmann IOP, is also plotted



along the y axis. The apparently parallel plots of each instrument with a constant error offset is evident. This parallelness is also evident from the regression curve equations (Figures 5-8). The CT-10 NCT II, AND XPERT NCT have nearly identical "m" (slope) factor constants. From Figures 9 and 10 it can be seen that all the air-puff tonometers measure higher than the Goldmann for IOP's below the mean. At normal IOP values, the PULSAIR remains the only low reading instrument, with the CT-10 and the XPERT NCT measuring slightly higher, and the NCT II measuring almost the same as Goldmann. When the IOP reaches the mid to high 20 mm Hg. values, all the air-puff tonometers except the PULSAIR, measured higher values than the Goldmann instrument. The erratic end-curve spiking is most likely the result of few and single data point plots in these IOP ranges.

The frequency of mean differences in IOP between all the air-puff tonometers and the Goldmann measurements are illustrated in Figures 11 and 12 and Table 3. The results for Group 1 and 2 are very similar. The results of all the air-puff tonometers except the Pulsair, form an almost normal distribution curve. The PULSAIR demonstrated the largest number of readings that differed from Goldmann, and the majority of those readings were consistently lower than the Goldmann values. The NCT II values had the least dispersion with 77% of all its values within  $\pm 3$  mm Hg and 89% within  $\pm 4$  mm Hg of the corresponding Goldmann findings.

A comparison of Range (maximum - minimum readings) values for all the instruments is illustrated by Figures 13 and 14. The PULSAIR shows a greater variation than any of the other air-puff

tonometers. A one factor ANOVA with a 90% level of significance for the Range comparisons between all air-puff instruments, found all comparisons except the CT-10 to XPERT and CT-10 to NCT II to be significantly different.

An analysis of the data to determine the repeatability of each tonometer was done. The results of the comparison of each instrument's first to last reading, first to mean reading and first to Goldmann mean reading was determined. These values along with correlation values between tonometers are shown in Tables 4 and 5. All instruments, except the Keeler PULSAIR, show a higher correlation between the 1st and mean values than the correlation of values between instruments. The PULSAIR had the lowest correlation values of any of the tonometers for either the between or within instrument considerations.

Although the testing sequence was randomized for each subject, the data were still analyzed for any possible pattern resulting from a particular order sequence. A one factor ANOVA with a 90% level of significance for the mean of each air-puff tonometer, sorted for when any instrument was used in the first, second, third or fourth position, revealed no significant difference or pattern. The same "no pattern" result was revealed when the data was examined for the comparison of each instrument's first, second and third readings.

Subject's responses to the air-puff instrument preference questionnaire are presented in Table 6 and Figures 15 and 16. The XPERT NCT was chosen as most preferred by the largest percentage ( 31% ) of the 168 subjects that completed the questionnaire. The instrument that has been around the longest, the NCT II, was the

least preferred by an even larger percentage ( 34% ) of the respondents. Predictably, the most frequent reason for preferring one instrument over another was the perceived magnitude of the applanating air-puff. In excess of 60% of the subjects attributed their choice for most and least preferred instrument to the level of comfort of the air-puff.

### Discussion

The purpose of this comparative study was to determine if any performance differences could be determined between air-puff tonometers and whether these instruments were variably accepted by the subject population. While the data collected in the study results in an affirmative answer to both questions, it is imperative to keep in mind the differences between statistically significant findings and clinically significant ones.

Data analysis reveals that the mean IOP values for all instruments, except the NCT II, were significantly different from the Goldmann mean IOP for both Groups 1 and 2. In Group 1 (298 eyes and all instruments) the Topcon CT-10 and Reichert XPERT NCT had higher mean IOP values than Goldmann ( +1.88 mm Hg and +1.12 mm Hg respectively ). The Reichert NCT II was only .23 mm Hg lower than Goldmann. The largest difference ( 2.38 mm Hg ) was found between the Keeler PULSAIR and Goldmann. Although the differences for all instruments were statistically significant, they were not clinically significant since they were all less than the variation expected due to the normal cardiac ocular pulse.<sup>14</sup>

The standard deviation of mean IOP differences (  $S_D$  ), was also calculated for each test instrument and the Goldmann tonometer

( see Table 1 & 2 ).<sup>15</sup> These values ( for Group 1 ) vary from a low for the Topcon CT-10 of  $\pm 2.66$  SD to a high of  $\pm 2.89$  SD for the Keeler PULSAIR. Although the SD do represent a more descriptive comparative measure than the means alone, they were not considered informative enough for this multi-instrument study.

The differences between instruments is best illustrated by Figures 9 and 10. The graphs for both Group 1 and Group 2 are virtually identical. For the majority of data points ( those  $< 24$  mm Hg ), the linear and almost parallel nature of the data is clearly evident. The results support the assumption that all the air-puff tonometers are measuring in a similar fashion. The question remains why these discrepancies exist? Is it simply that the calibration settings for each instrument are slightly varied, or is there something fundamentally different about applanating the cornea with a puff of air rather than a Goldmann tonometer tip?

Although such factors as applanation time (seconds for Goldmann, 1-3 milliseconds for NCT), area of applanation (3.06 mm of diameter for Goldmann, 3.6 mm for NCT), and force required for applanation (1 gram per 10 mm Hg for Goldmann, 1.4 grams per 10 mm Hg for NCT) are different for air-puff and Goldmann tonometers, the overall force/unit is the same for the two types. The difference in impact-times between the two instruments is considered the primary factor responsible for the absence of pressure reduction with successive air-puff measurements.<sup>7</sup> The close correlation between the slopes of each instrument when compared to Goldmann, with offsets of 1-2 mm Hg / instrument, supports the hypothesis that a difference in instrument calibration is responsible for our differences between

air-puff tonometers. The consistent differences in slopes between all air-puff tonometers and Goldmann best supports the hypothesis of an inherent difference between Goldmann and air-puff tonometry in general. This should be a topic of future studies.

When comparing the individual performance of each air-puff instrument we found that the NCT II had the most normal distribution when compared to Goldmann ( Figures 11 and 12 ). For Group 2 the mean IOP value differed from Goldmann by only .02 mm Hg, with the smallest mean Range value for all air-puff instruments of 2.12 mm Hg. These results support previous studies that have established the NCT as being reliable for measuring IOP within the normal IOP range.<sup>4,5,7</sup> Although several studies have established the NCT as reliable in higher pressure ranges<sup>5,12</sup>, this study cannot confirm those findings. From the limited data points available it appears that a trend for the NCT II to read higher than Goldmann beyond the mid 20 mm Hg values exists.

The XPERT NCT closely paralleled the performance of the NCT II. The XPERT's readings were slightly higher than the equivalent NCT II findings and also had larger mean Range values of 2.54 mm Hg.

The Topcon CT-10 consistently measured higher than Goldmann, with the 2nd lowest overall mean Range value of 2.19 mmHg. Similar results were recently reported by Verdoorn and Dentman, although they reported a smaller SpD value (2.15 versus 2.60 in this study).<sup>13</sup>

Consistent with previous reports, the Keeler PULSAIR in this study read high at lower pressures and low at higher pressures.<sup>6,8,11</sup> The mean Range for Keeler ( 5.42 mm Hg ) was quite a bit higher than all other air-puff tonometers. A more recent

investigation of the Keeler PULSAIR by Sponsel, et.al. also reported that, "...the Pulsair tended to read low at IOP above the normal range". In that study, the PULSAIR was evaluated against the Goldmann in cannulated post mortem human eyes, and in living subjects at three clinical centers. Results are reported mainly as coefficients of correlation, ranging from .79 to .97 between Goldmann and PULSAIR IOP readings. The high  $r=0.97$  value was determined by comparing the mean of three PULSAIR readings to the manometric pressure as regulated in the cannulated eyes. Unfortunately, this high coefficient of correlation is not realistic, since according to the author, "Data analyses were ... performed using the mean of only the upper three PULSAIR readings at each manometric setting". In one of the clinical studies (Madison) using living subjects, an  $r=0.97$  value is again reported. In this study the mean PULSAIR was obtained by using only the first, fourth, and fifth PULSAIR readings. Correlations found in the other studies are much lower ( $r=0.79$  Milwaukee,  $r=0.80$  Seattle). The reader is left to make the assumption that these lower values were obtained as the result of not discarding any of the PULSAIR readings.<sup>11</sup> The Milwaukee and Seattle correlation coefficients are similar to this study's findings of +0.76 for Group 1 and +0.74 for Group 2.

Of greater interest though, then the coefficients of correlation reported by the Sponsel study, is the observation that while testing the post mortem eyes, and using artificial tears to prevent corneal dessication, "... occasional very low artifactual readings were obtained with the PULSAIR, possibly resulting from irregularities in the devitalized corneal epithelium." This may be analogous to the

situation which occurs in living subjects (i.e. disparate readings due to low TBUT). These induced spurious readings would be eliminated for all instruments with a built-in low confidence reading detector (CT-10, NCT II, and XPERT NCT ) but not for the PULSAIR ( no detector ). This seems a more plausible explanation than attributing the spread of the individual readings to phase variations of the ocular pulse (usually  $< 4$  mm Hg).<sup>14</sup>

In a 1989 study by Mosely, Evans and Fiedler, it was reported that on a comparison of 182 eyes, using three Goldmann to five PULSAIR readings, coefficient of correlation ( $r$  ) values of .90 for the median and .91 for the mean were determined. PULSAIR measurements falling within  $\pm 3$  mm Hg of Goldmann measurements varied from 59- 62% for the mean values and 65-71% for the median data. The authors concluded that the median of five PULSAIR readings was a better comparison to Goldmann than the mean of either four or five readings. This recommendation should be considered by Keeler instruments, who presently recommend taking the mean of four readings regardless of their values.<sup>8</sup>

When using instruments where the "true" measurement is based on the mean or median of multiple repeated measures, there exists the possibility of obtaining a false reading if fewer than the recommended number of readings are performed. In situations where only one reading is obtainable the correlation between the first and the mean reading will be important. It is evident that all the air-puff tonometers, except the Keeler PULSAIR, demonstrated good repeatability between the first and mean values ( see Tables 4 & 5 ).

The two reasons for including a preference questionnaire in the

study were to determine if any correlation existed between the manufacturer's expectations for their design changes and the subject's acceptance and perception of those changes, and secondly, to determine whether the subjects could in fact distinguish one air-puff tonometer from another.

Based on the results ( Table 6 ), manufacturers of the new series of air-puff tonometers have apparently succeeded in producing a more comfortable tonometer. The largest percentage of subjects (31%) preferred the XPERT NCT. The NCT II was chosen as least preferred of all air-puff tonometers.

From this study we conclude that the new generation of air-puff tonometers (Topcon CT-10, Reichert XPERT NCT, and Keeler PULSAIR) do offer significant design improvements over the NCT and NCT II models. Factors such as softer air-puff, increased portability (Keeler PULSAIR only), auto measurement mode, built in printer (Topcon CT-10 and XPERT NCT), and increased patient acceptance, are welcome additions to this frequently used ophthalmic instrument.

While design changes have improved ease of use and patient comfort, the accuracy and reliability of performance of the new models showed no improvement when compared to the older NCTII. It is unfortunate that the Keeler PULSAIR, which has the most innovative design, and is the most portable and useful for bed-fast and younger patients, demonstrated the poorest performance of any of the air-puff tonometers. Due to clinically unacceptable variability and consistently low readings, even in the normal IOP range, its value as a screening instrument must be suspect. It is hoped that with continuing efforts by the manufacturer, the Keeler



PULSAIR will achieve the accuracy and reliability of the other air-puff tonometers.

The air-puff tonometer has traditionally been most widely used as a screening test instrument for glaucoma.<sup>7</sup> The importance of intraocular pressure is currently being viewed more in terms of a "risk factor" rather than as a diagnostic indicator for glaucoma. However, until newer psychophysiological methods of testing for glaucoma ( color threshold, nerve-fiber layer evaluation, etc. ) are clinically perfected and validated, the use of air-puff tonometry will continue to be an important part of the ocular examination procedure.

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## Footnotes

- a. Keeler PULSAIR Tonometer  
Keeler Instruments, Inc.  
456 Parkway, Broomall, PA 19008  
800-523-5620  
List Price ( Dec. 1989 ) : \$3,995.00  
Notes : Keeler is planning the addition of a hardcopy printer to the late 1990 models.
- b. Topcon CT-10 Tonometer  
Topcon Instrument Corporation of America  
325 North Wiget Lane  
Walnut Creek, CA 94598  
415-947-4800  
List Price ( Dec. 1989 ) : \$8,490.00  
Notes : In July 1989, Topcon replaced the CT-10 with the CT-20 model. The manufacturer claims the newer model is quieter and has a gentler applanating air puff.
- c. Reichert NCT II and XPERT NCT Tonometers  
Cambridge Instrumenmts Inc.  
P.O. Box 123  
Buffalo, N.Y. 14240  
716-891-3000  
List Price ( Dec. 1989 ) : \$6,795.00 Reichert NCT II  
\$8,495.00 Reichert XPERT NCT
- d. A test-retest Goldmann Applanation Tonometry study was conducted, with fifteen randomly selected non-study subjects (30 eyes), by the examiner and another military optometrist with 12 years clinical experience. Each subject had three blind readings taken per-eye by

- d. each examiner ( examiner order was alternated ). Data analysis for the mean IOP measurements of the two examiners follows:

$n = 30$

$SDIFF = 1.60 \text{ mm Hg}$

coefficient of correlation = .84

Similar results for Goldmann repeatability were reported by Thorburn in an investigation comparing two operators, one Goldmann instrument, and two immediate successive sets of measures.<sup>18</sup>

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## Appendix A - Instrument numbering

1. CT-10 (Topcon)
2. XPERT NCT (Reichert)
3. NCT II (Reichert)
4. PULSAIR (Keeler)
5. GOLDMANN (HaagStreit)

FIGURE 1. Topcon CT-10





FIGURE 2. Reichert XPERT NCT



FIGURE 3. Reichert NCT



FIGURE 4. Keeler PULSAIR

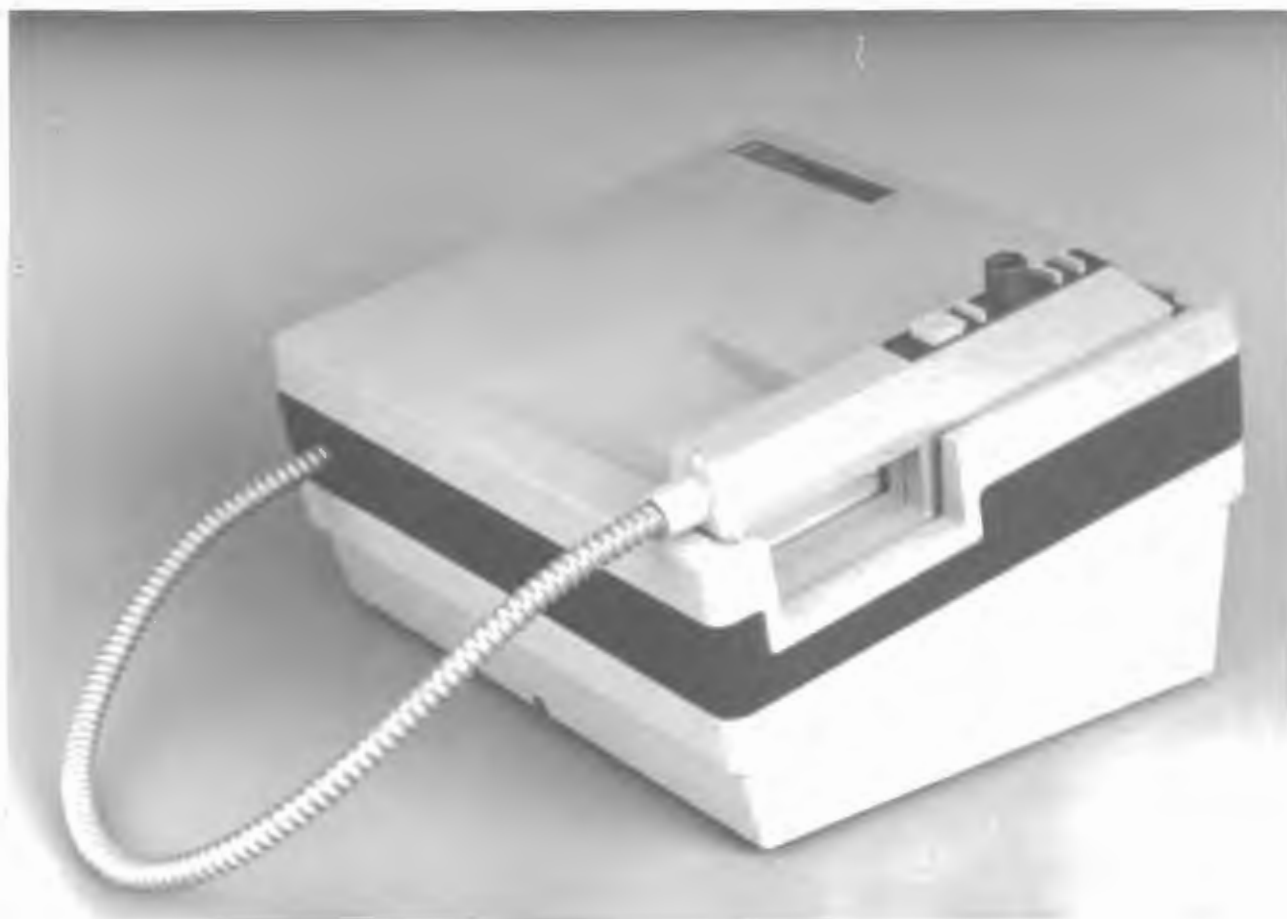


FIGURE 4. Keeler PULSAIR



TABLE 1. Comparison of All air-puff tonometers and Goldmann Applanation Tonometer, Group 1 (298 eyes)

INSTRUMENT	MEAN IOP	S.D.	MEAN RANGE	S.D.	MINIMUM RANGE	MAXIMUM RANGE	SD
Topcon CT-10	16.32	4.59	2.19	1.29	0	9	2.66
Reichert XPert NCT	15.56	4.58	2.54	1.73	0	18	2.79
Reichert NCT II	14.21	4.58	2.12	1.47	0	12	2.74
Keeler PULSAIR	12.06	3.99	5.42	2.94	0	22	2.89
GOLDMANN	14.44	4.22	.92	.92	0	5	

TABLE 2. Comparison of CT-10, NCT II, PULSAIR, and Goldmann Applanation Tonometer, Group 2 (452 eyes)

INSTRUMENT	MEAN IOP	S.D.	MEAN RANGE	S.D.	MINIMUM RANGE	MAXIMUM RANGE	SD
Topcon CT-10	16.33	4.29	2.11	1.29	0	9	2.60
Reichert NCT II	14.14	4.26	2.15	1.47	0	7	2.66
Keeler PULSAIR	12.08	3.94	5.55	2.94	0	12	2.89
GOLDMANN	14.16	3.80	1.30	.92	0	1	

TABLE 3. Percentage of Air-Puff Mean IOP's within  $\pm 3$  mm Hg or  $\pm 4$  mm Hg of corresponding Goldmann Mean IOP's.

	<u>GROUP 1 (1-298 EYES)</u>		<u>GROUP 2 (1-452 EYES)</u>	
	$\pm 3$ mm	$\pm 4$ mm	$\pm 3$ mm	$\pm 4$ mm
CT-10(TOPCON)	70%	81%	69%	82%
XPERT NCT (REichert)	72%	85%	--	--
NCT II (REichert)	77%	89%	80%	91%
PULSAIR (KEELER)	59%	72%	63%	76%

TABLE 4. Correlation coefficients (r)  
between instrument's individual readings and between  
instruments  
Group 1 (298 eyes)

READINGS ->	1st to last	1st to Instrument mean	1st to Goldmann mean	Instrument mean to Goldmann mean
INSTRUMENTS				
Topcon CT-10	+0.91	+0.97	+0.80	+0.82
Reichert XPERT NCT	+0.89	+0.96	+0.78	+0.81
Reichert NCT II	+0.91	+0.97	+0.79	+0.81
Keeler PULSAIR	+0.65	+0.84	+0.68	+0.76
GOLDMANN	+0.95	+0.98	+0.98	+1



TABLE 5. Correlation coefficients (r) between instrument's individual readings and between instruments  
Group 2 (452 eyes)

READINGS ->	1st to last	1st to Instrument mean	1st to Goldmann mean	Instrument mean to Goldmann mean
INSTRUMENTS				
Topcon CT-10	+0.91	+0.97	+0.78	+0.81
Reichert NCT II	+0.90	+0.96	+0.77	+0.80
Keeler PULSAIR	+0.62	+0.83	+0.66	+0.74
GOLDMANN	+0.94	+0.98	+0.98	+1.0

TABLE 6. Summary of the data from the Instrument Preference Questionnaire

INSTRUMENT Preferred the MOST	NUMBER OF SUBJECTS	PERCENTAGE
TOPCON CT-10	33	20%
Reichert XPERT NCT	53	31%
Reichert NCT II	21	12%
Keeler PULSAIR	38	23%
No Choice	23	14%

INSTRUMENT Preferred the LEAST	NUMBER OF SUBJECTS	PERCENTAGE
TOPCON CT-10	23	14 %
Reichert XPERT NCT	17	10%
Reichert NCT II	56	34%
Keeler PULSAIR	37	22%
No Choice	33	20%

FIGURE 5. Correlation (+0.82) of IOP measured with the CT-10 and the Goldmann Applanation Tonometer from a sample of 298 eyes (Group 1)

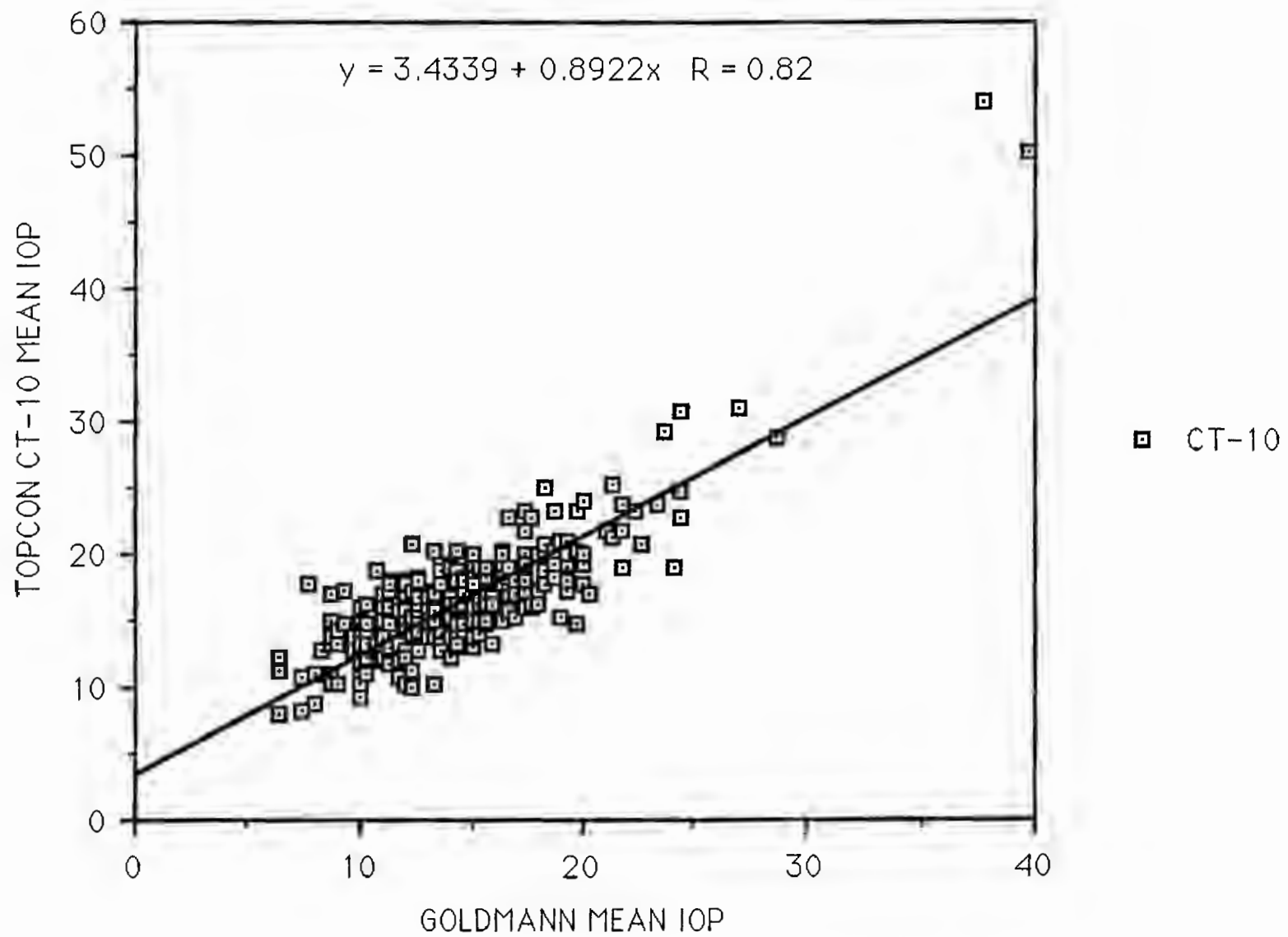


FIGURE 6. Correlation (+0.81) of IOP measured with the XPERT NCT and the Goldmann Applanation Tonometer from a sample of 298 eyes (Group 1)

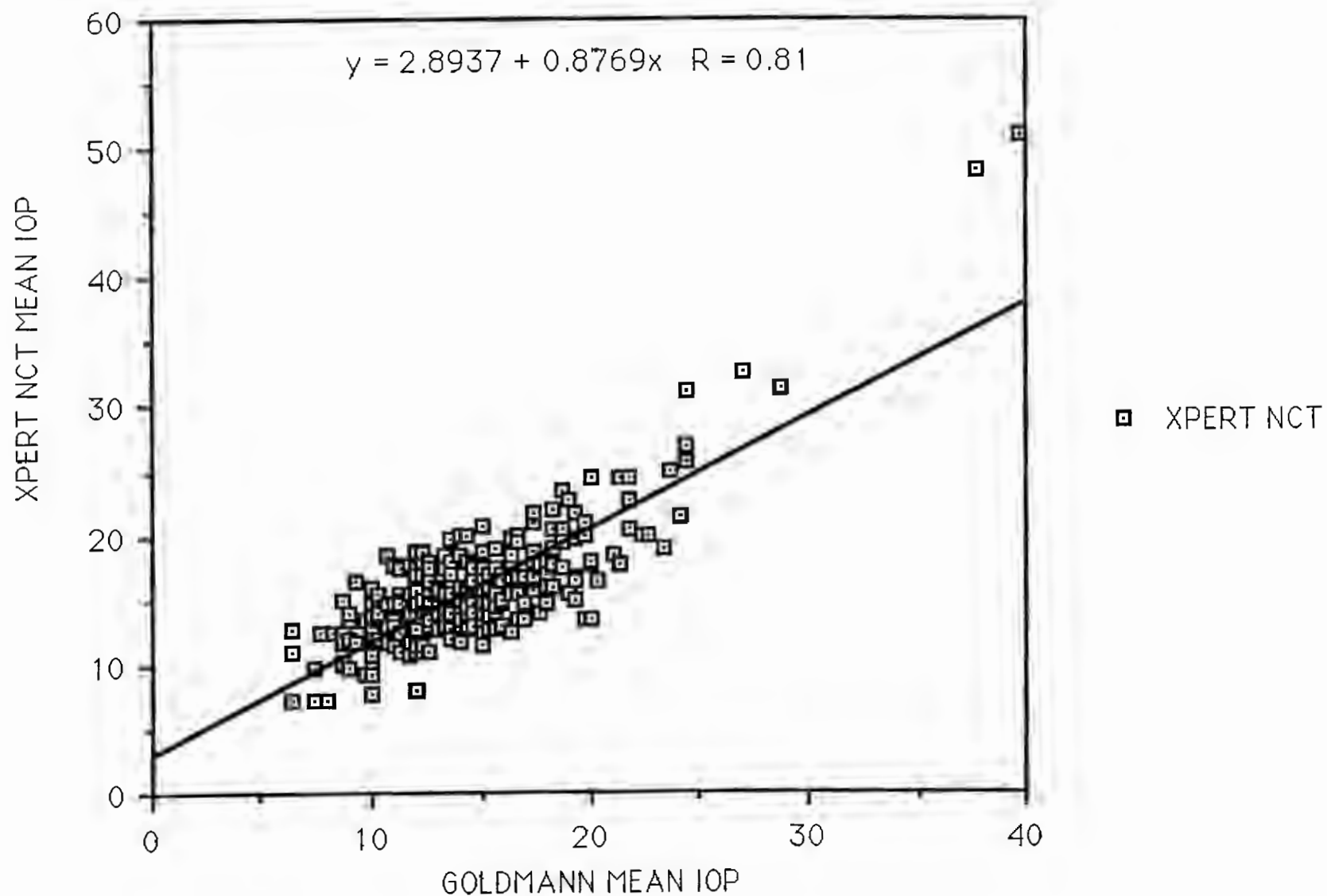


FIGURE 7. Correlation (+0.81) of IOP measured with the Reichert NCT II and the Goldmann Applanation Tonometer from a sample of 298 eyes (Group 1)

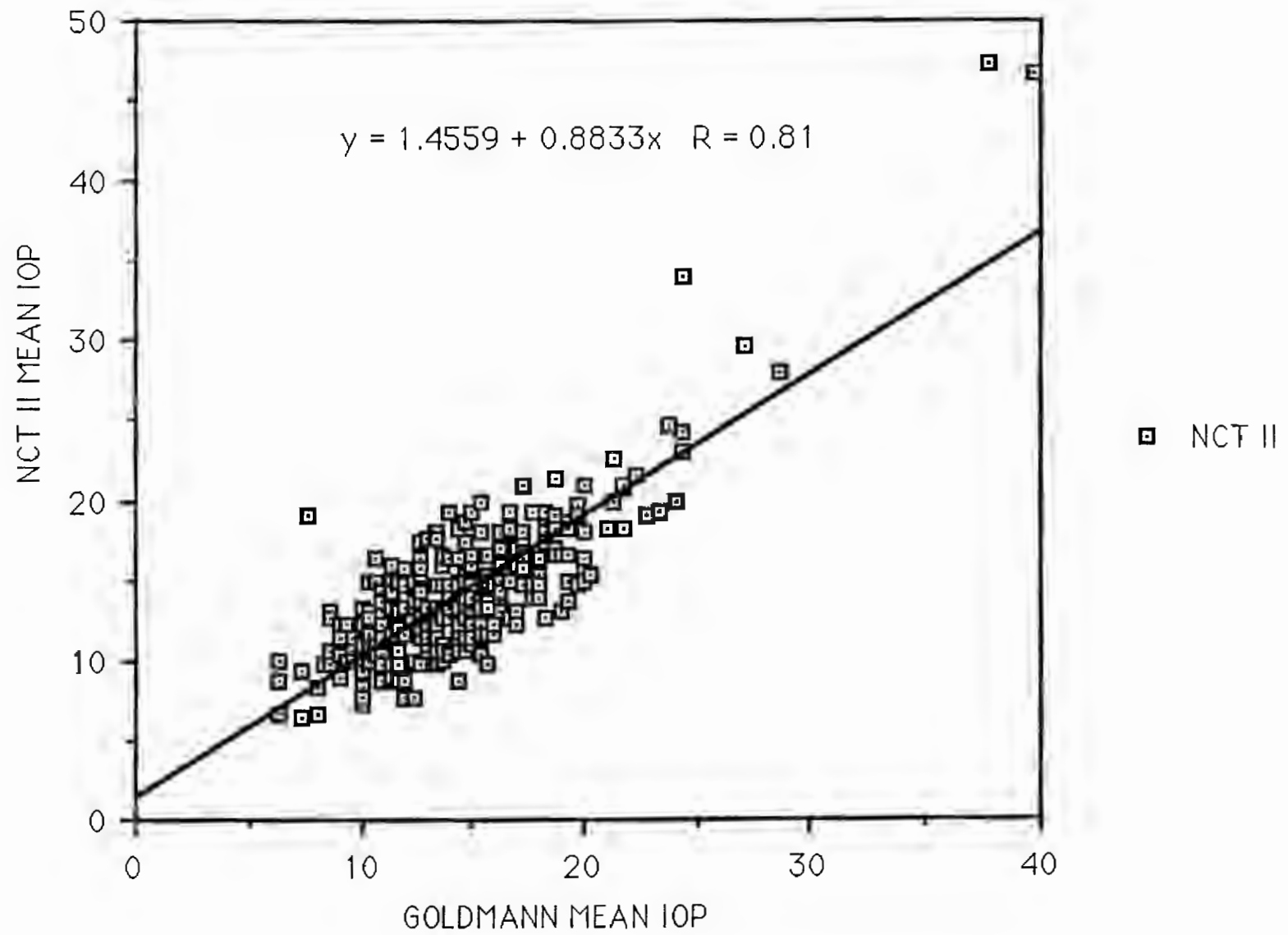


FIGURE 8. Correlation (+0.76) of IOP measured with the Keeler PULSAIR and the Goldmann Applanation Tonometer from a sample of 298 eyes (Group 1)

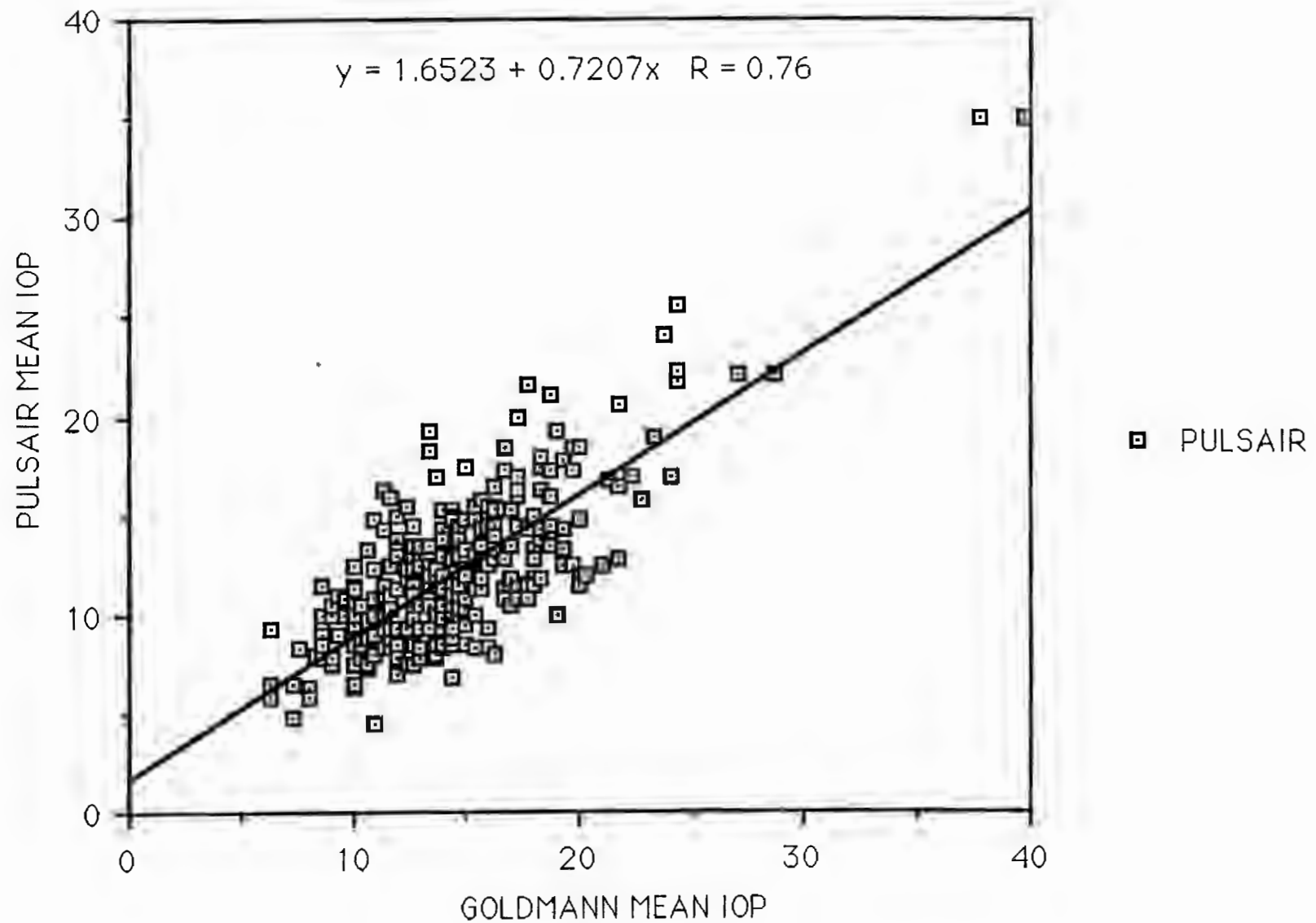


FIGURE 5a. Correlation (+0.81) of IOP measured with the CT-10 and the Goldmann Applanation Tonometer from a sample of 452 eyes (Group 2)

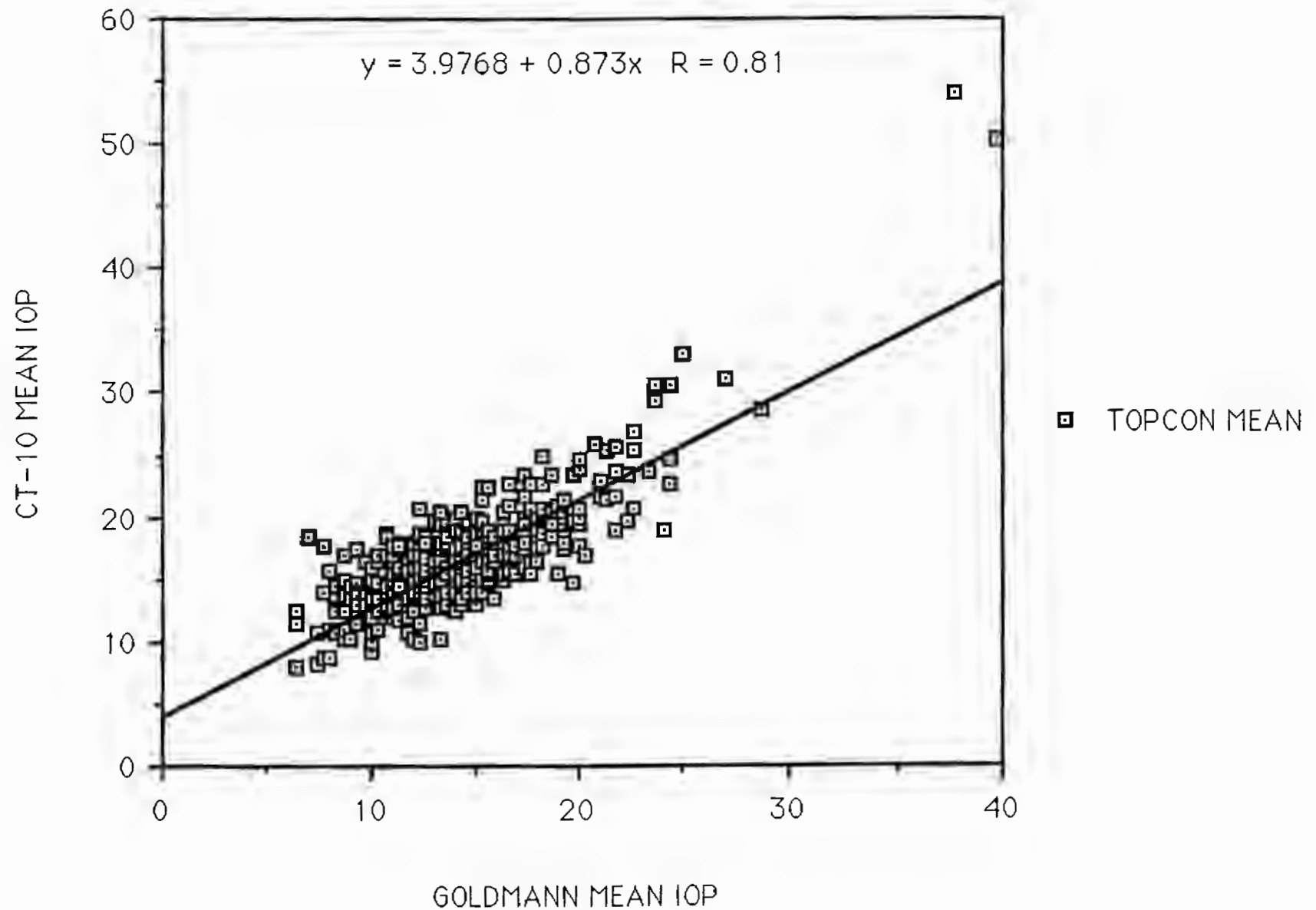


FIGURE 6a. Correlation (+.80) of IOP measured with the NCT II and the Goldmann Applanation Tonometer from a sample of 452 eyes (Group 2)

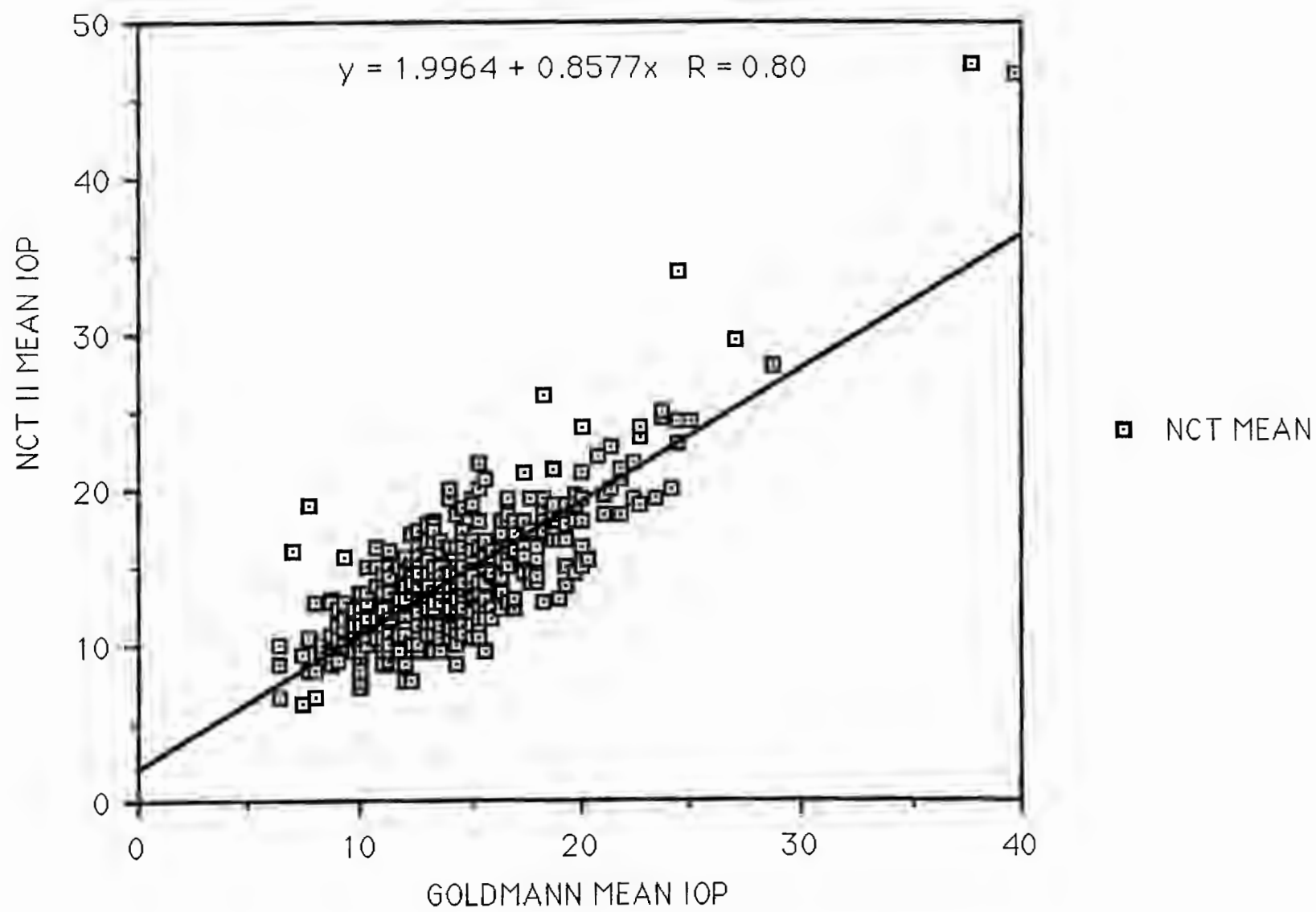




FIGURE 7a. Correlation (+0.74) of IOP measured with the PULSAIR and the Goldmann Applanation Tonometer from a sample of 452 eyes (Group 2)

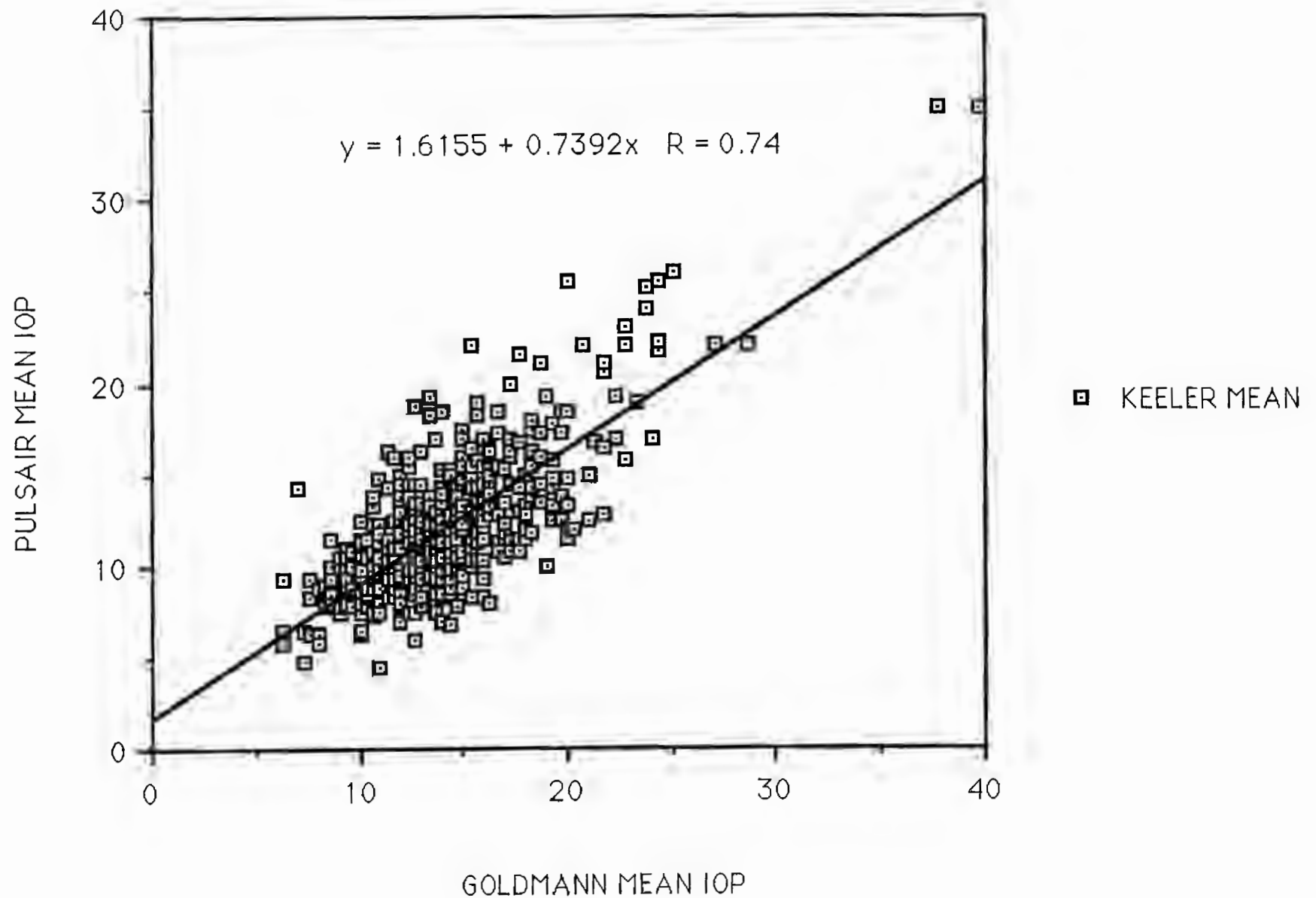


FIGURE 9. Mean differences from Goldmann - Group 1 (298 eyes)

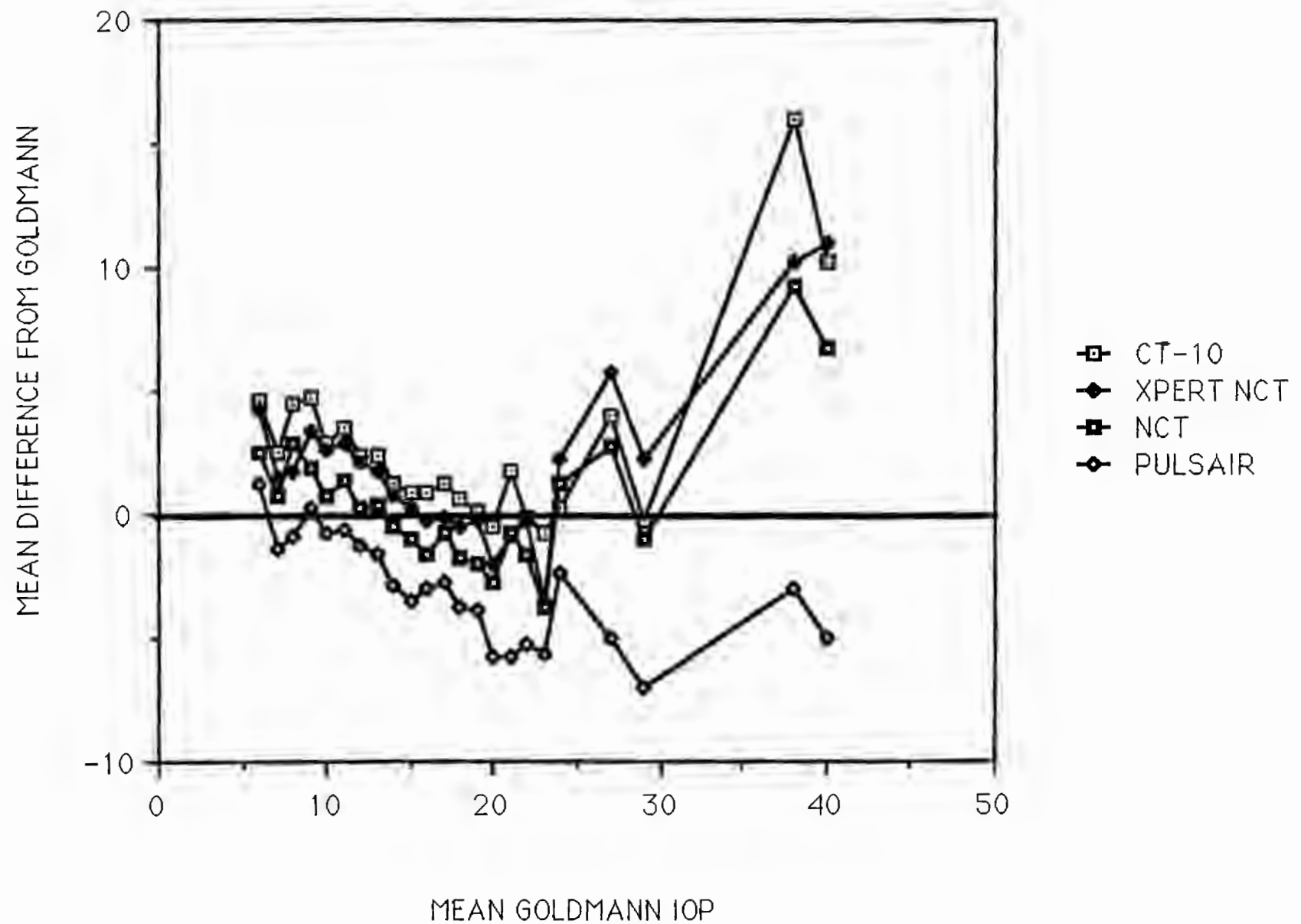


FIGURE 10. Mean differences from Goldmann – Group 2 (452 eyes)

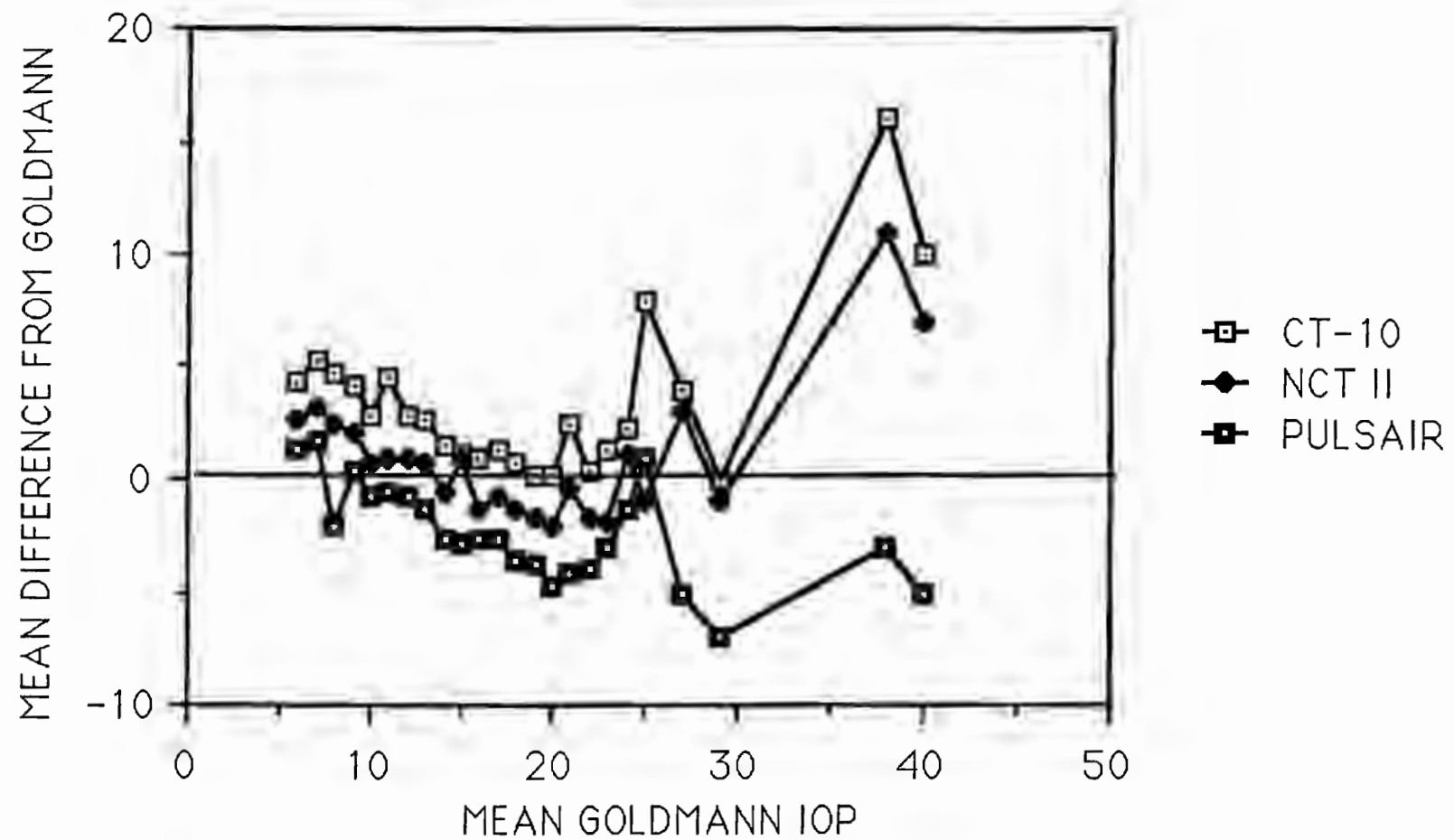


FIGURE 11. Frequency of the differences in mean IOP values  
between all air-puff tonometers and Goldmann Applanation Tonometer  
Group 1 (298 eyes)

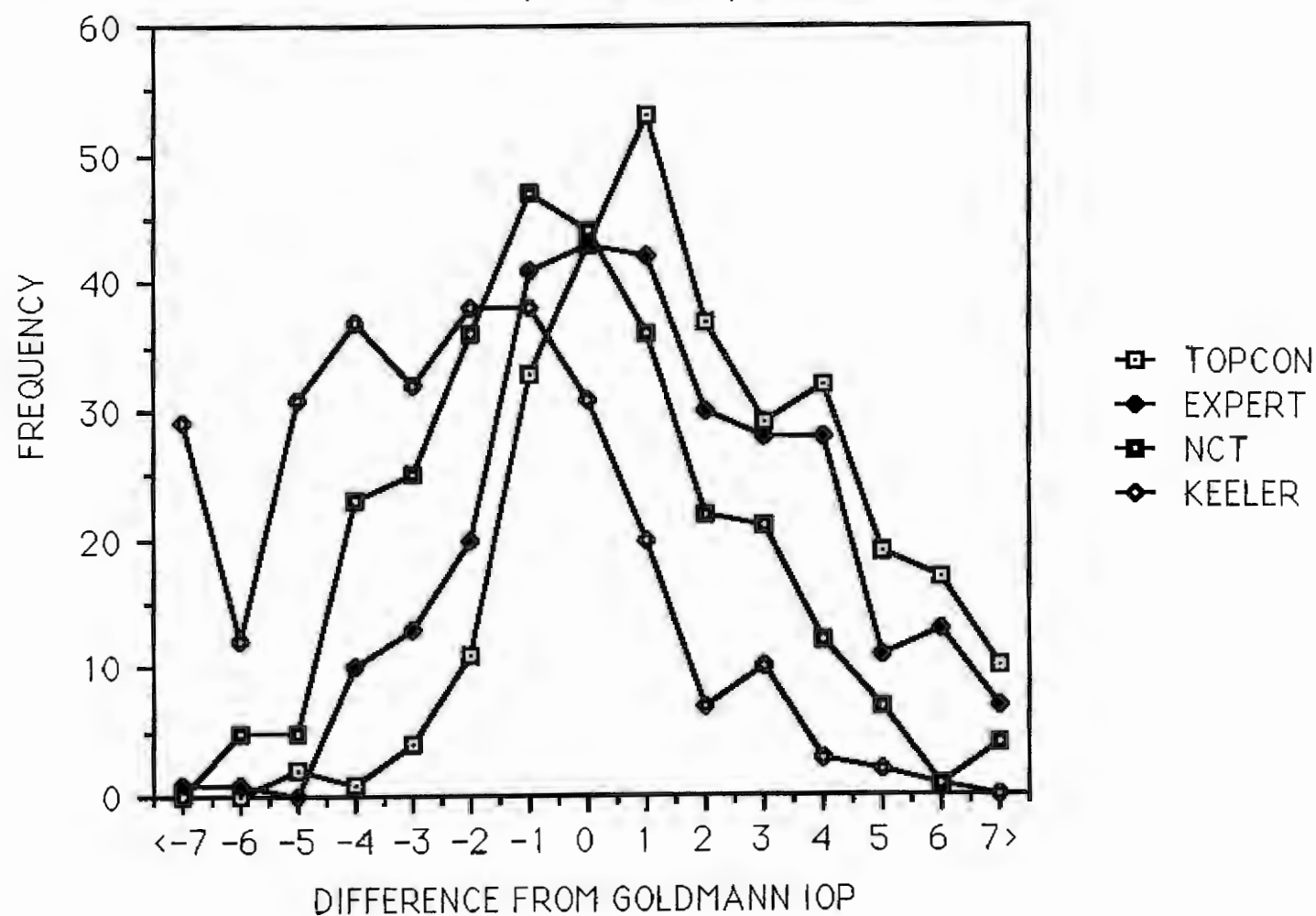


FIGURE 12. Frequency of the differences in mean IOP values between three air-puff tonometers and Goldmann Applanation Tonometer Group 2 (452 eyes)

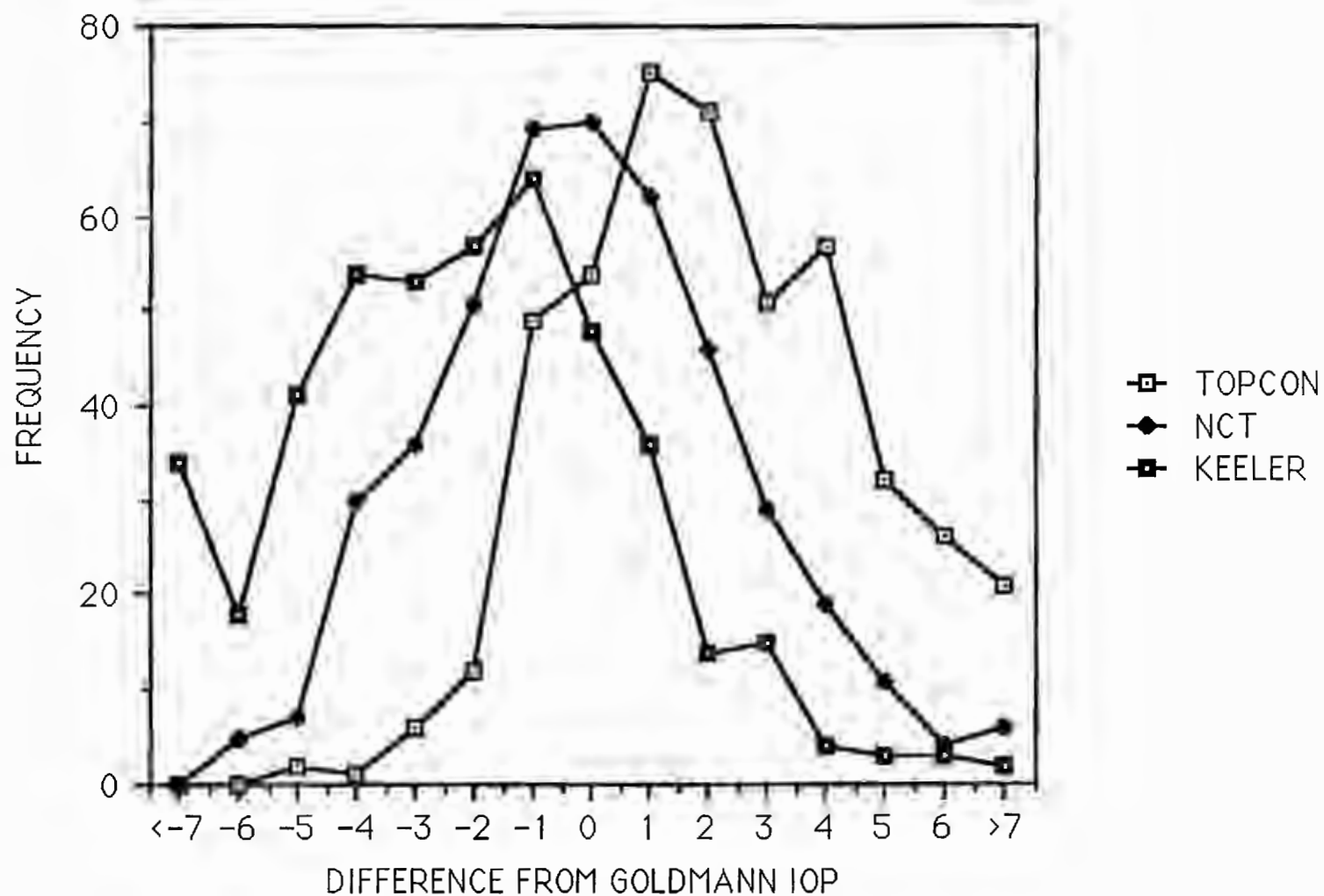


FIGURE 13. Comparison of Range values for all air-puff tonometers  
Group 1 (298 eyes)

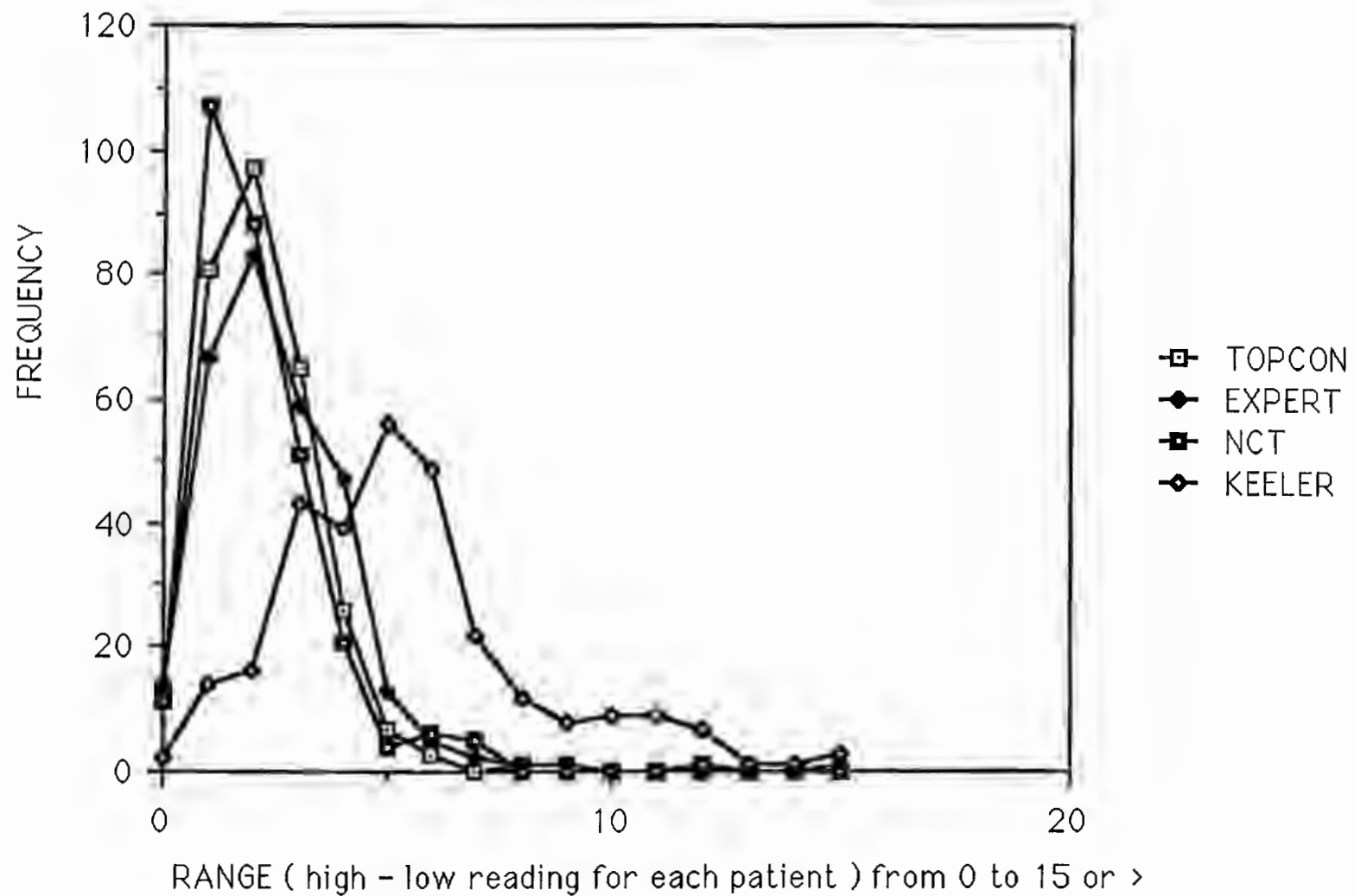


FIGURE 14. Comparison of Range values for three air-puff tonometers  
Group 2 (452 eyes)

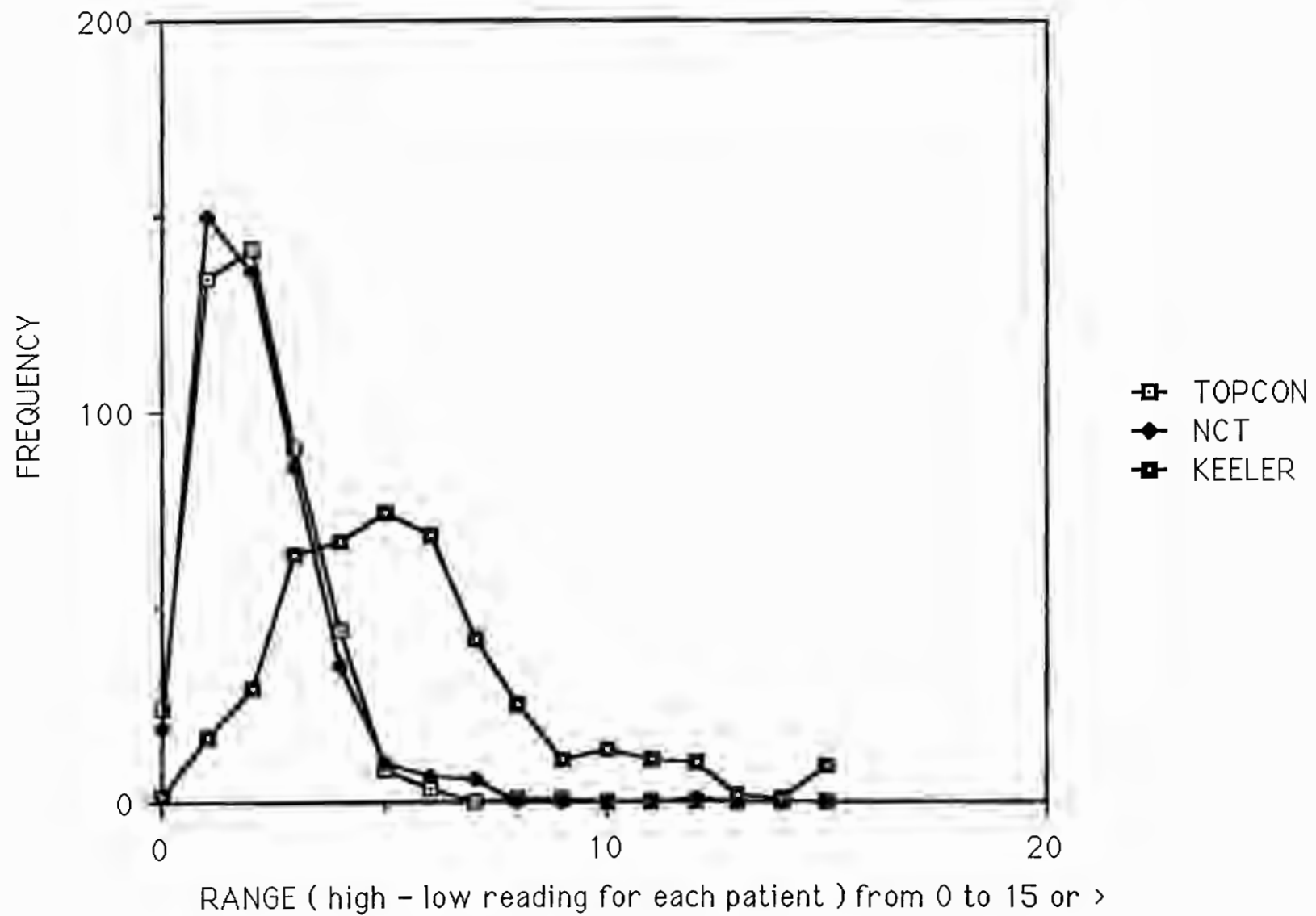


FIGURE 15. Air-puff tonometer preferred the most ( 168 subjects )

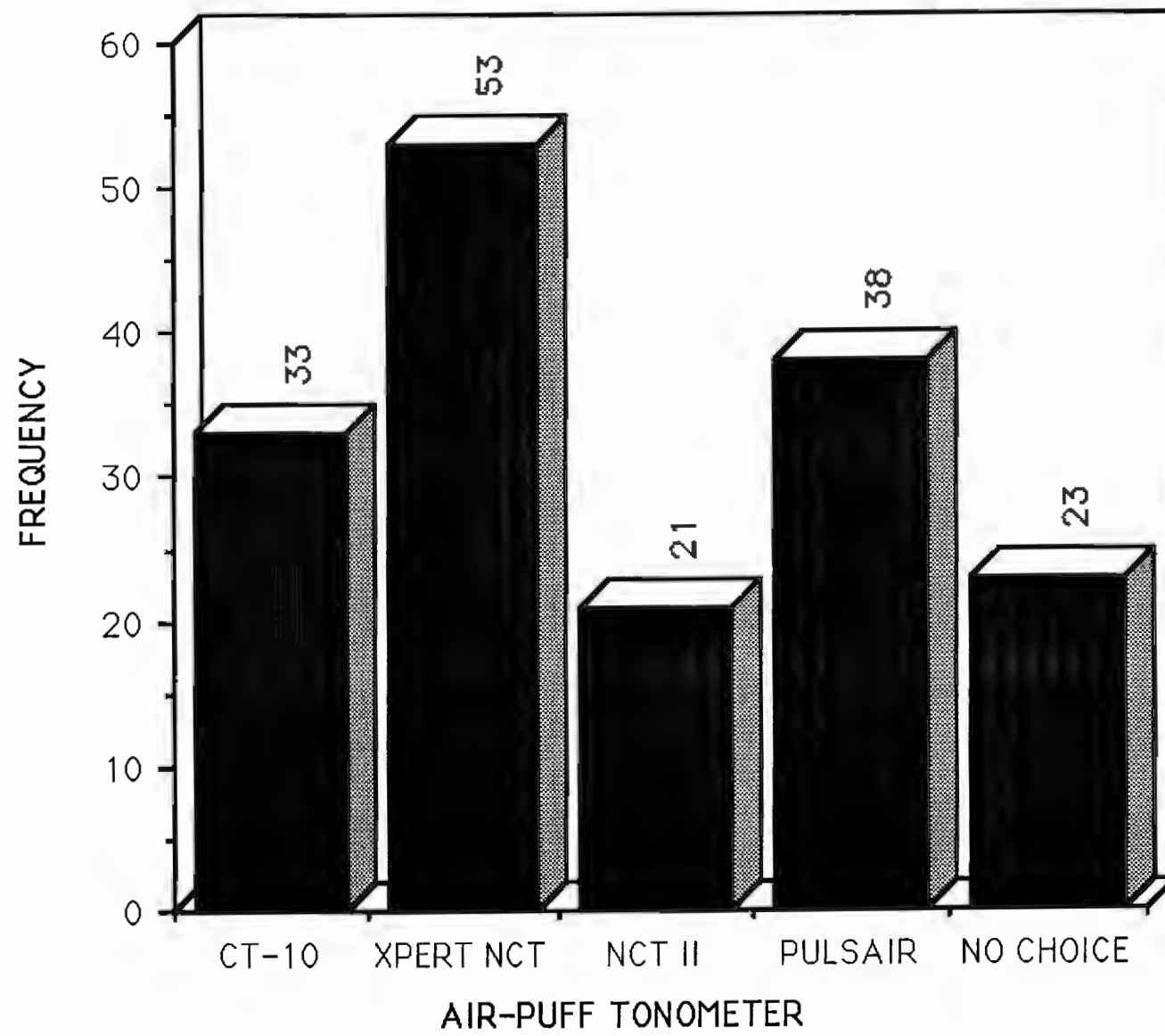




FIGURE 16. Air-puff tonometer preferred the least ( 168 subjects )

